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COMPARISON OF GROUND AND AERIAL ULTRA-LOW VOLUME APPLICATIONS OF MALATHION AGAINST *AEDES AEGYPTI* IN SANTO DOMINGO, DOMINICAN REPUBLIC[1]

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ABSTRACT. Efficacy of ground and aerial ultra-low volume (ULV) applications of 91% malathion at 438 ml/ha against *Aedes aegypti* in the Dominican Republic was evaluated using indoor collections, oviposition trapping and adult sentinel mortality rates. Ground compared to aerial ULV applications in this study were found to have a greater effect on *Ae. aegypti* when measured by the described sampling techniques. Neither application method provided the level of *Ae. aegypti* suppression believed necessary for control in the event of a dengue virus epidemic.

INTRODUCTION

The principle vector of dengue viruses is *Aedes aegypti* (Linn.) (Harwood and James 1979). Rigorous environmental sanitation and source reduction are the proven long-term control methods against *Ae. aegypti*, but these methods are neither routinely nor uniformly practiced in many nations. Even with a long-term vector control program, natural catastrophes (hurricanes, floods and earthquakes) and man-made disasters (wars) create conditions favorable for large *Ae. aegypti* populations, which can lead to epidemic outbreaks of dengue and dengue hemorrhagic fever. Once an epidemic is in progress, the goal is to adequately reduce the adult *Ae. aegypti* density as quickly as possible, thereby interrupting transmission of the virus to uninfected hosts. This indicates the need for effective control methods against adult *Ae. aegypti* populations which can be implemented when an epidemic occurs.

Ultra-low volume (ULV) application of various adulticides is the recommended control method against *Ae. aegypti* in the Americas (Gigliolí 1979, PAHO 1981). Both ground and aerial ULV insecticide applications have been reported effective during outbreaks of dengue in the Bahamas (Charles et al. 1979), Cuba (PAHO 1982, Tonn et al. 1982) and Puerto Rico (Chiriboga et al. 1979). However, assessment of the contribution of ULV spraying to lowering transmission rates was impossible due to various factors, including simultaneous use of larviciding and community clean-up campaigns combined with adulticiding along with ULV application after the epidemic peaked (Moody et al. 1979, Morens et al. 1986). Other studies have reported failures of ULV adulticiding for control of *Ae. aegypti* (Fox 1980, Chadee 1985, Hudson 1986).

There has not been reported in the literature any direct comparison between the effectiveness of ground and aerial ULV application methods against *Ae. aegypti* in a tropical urban environment. The objective of this study was to compare ground and aerial ULV applications of malathion against adult *Ae. aegypti* populations in Santo Domingo, Dominican Republic, using standard assessment techniques and in the absence of additional control measures (larviciding, source reduction and environmental sanitation).

MATERIALS AND METHODS

The study was done in discrete urban residential areas of Ensanche Espaillat, Santo Domingo, Dominican Republic. Three areas of similar size (11.5 ha, approximately 24 blocks) and housing characteristics were selected. The areas were approximately 500 m apart, and locations in relation to each other (offset) were selected to minimize pesticide drift between areas.

Typical houses in the treatment areas were one story, stucco or cement block dwellings, with 2 or 3 bedrooms, a living room in the center and a backroom kitchen. A 1-m high stone or cement block wall, approximately 5 m from the center of the street, was located the length of the front

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of each home. Homes had a small courtyard area behind the wall which contained various plants 0.5–2.0 m high along with 1 to 2 tropical trees ranging from 10 to 15 m high. In the rear of the houses, uncovered 55-gal metal drums lined with cement and used for water storage were found to be the primary *Ae. aegypti* larval source.

Both ground and aerial applications were made using 91% malathion (Cython®), at a rate of 438.8 ml/ha [6 fl oz/acre (500 g[AI]/ha)], to the 6-block center portion of the 2 areas designated for treatment. The third area served as an untreated control. Malathion was selected because of local vector susceptibility, environmental safety, public acceptance and cost.

Resistance studies 3 months prior to this study were conducted in accordance with standard World Health Organization procedures (WHO 1981). *Aedes aegypti* populations from Santo Domingo, Dominican Republic, were determined to be 100% susceptible to malathion.

Ground and aerial treatments were initiated simultaneously at 1700 h on July 8, and 1900 h on July 12, 1988. An additional aerial treatment was made at 0845 h, on July 22, 1988, to determine if application time had any effect. No morning ground application was done because previous work found (Tidwell, unpublished data) no difference in effect between morning or afternoon ground spraying on *Ae. aegypti* populations in Santo Domingo. Doors and windows of homes in both treatment areas were opened completely before applications were begun. Application time corresponded approximately to peak *Ae. aegypti* biting activity, allowing for maximum potential insecticide:vector contact (Chadee 1988). Wind speed, wind direction and ambient air temperature were recorded at the start of each application.

Ground ULV applications were made using 2 truck-mounted LECO Model ULV-500 generators (Lowndes Engineering Co., Valdosta, GA) mounted in the same truck and operated simultaneously while traveling at 8 kph through the treatment area. Each machine was calibrated immediately before each treatment to dispense 219.4 ml/ha. The volume median diameter (VmD) output was checked before starting treatment using standard slide wave technique. The VmD was found to range from 10.5 to 21.0μm.

Aerial ULV applications were made using a standard U.S. Army Helicopter Slung Pesticide Dispersal Unit configured with 2 Beecomist Model 361A spray heads (Beecomist Systems, Inc., Telford, PA). The dispersal unit was calibrated before each treatment to apply 438.8 ml/ha and was slung beneath a Dominican Republic Air Force Utility Helicopter (UH-1) which flew at 110 kph, approximately 30 m above ground level. A swath width of 46 m was the flight path interval flown by the helicopter, corresponding to the approximate distance between streets. Swath width tests were made prior to treatment applications using oil-sensitive cards placed at 8-m intervals for 150 m in both open and urban areas. The open area was a zone of 100 m on either side of the airstrip which was totally devoid of structures and vegetation over 6 cm tall. No appreciable difference in average droplet number (4.5 drops/cm^2) or maximum swath width (144 m, 136 m) was found between open and urban areas.

Battery-powered spinning droplet collectors with 2 teflon coated slides per spinner were used to monitor malathion droplet sizes and distribution. The spinners were located in the back room of 5 randomly selected houses within the 6-block center portion of the treatment areas. In addition, a spinner was placed outside the front of 2 randomly selected homes in each treatment area, approximately 10 m from street center. Each home in which a spinner was placed also had one 18.5-cm diam filter paper placed approximately 15 cm from the back-room spinner and another paper placed beneath the bed of a front bedroom. Filter papers were also placed in front of 5 homes, 10 m from the center of each sprayed street in each treatment area. Slides and filter papers in the 2 treatment areas were retrieved within 30 min after completion of the insecticide applications. Slides were placed into plastic slide boxes (15 × 23 mm), returned to the laboratory, and VmDs were calculated by a computer program described by Boobar et al. (1986). Each filter paper was placed into a plastic bag, returned to the laboratory and the insecticide extracted and quantified using a variation of the gas chromatographic methods described by Hammarstrand (1976).

Efficacy of the ground and aerial adulticiding was monitored during the study by the following 3 procedures.

Adult collections: Twenty-five randomly selected homes within the 6-block center portion of all treatment areas were sampled for adult *Ae. aegypti.* Two men, starting at 0900 h, collected samples continuously for 5 min in each house with 30.5-cm diam sweep nets, collecting under tables, beds and in closets. All mosquitoes captured were identified, the number of *Ae. aegypti* recorded by sex and then all specimens were released. Sampling was performed daily for 3 days pretreatment and for 1 day posttreatment (the morning after the spray).

Data were analyzed by an analysis of variance procedure (ANOVA [SAS/STAT 1985]). The pre- and posttreatment means of adult *Ae. aegypti* for each sex were calculated for collections made from the ground, aerial and treatment control areas. Adult collection means were sep-

arated by use of Duncan's (1955) multiple range test (ANOVA [SAS/STAT 1985]) ($P < 0.05$). The percentage changes were calculated from [(posttreatment number − pretreatment number)/pretreatment number] × 100.

Ovitrap collections: Each of the 25 houses used for adult collections in the 3 treatment areas also had an ovitrap placed outside in an area protected from direct sunlight to monitor ovipositional activity as an indicator of adult gravid female densities. An ovitrap consisted of 150 ml of well water in a 400-ml black plastic cup with a 2- × 12.5-cm hardboard paddle similar to that described by Thaggard and Eliason (1969) clipped to the edge. Paddles and water were replaced daily, and the eggs attached to the paddles were counted using a stereomicroscope at 20× magnification. Eggs were not identified to species due to *Ae. aegypti* being the only species in the Dominican Republic which oviposits in artificial containers. Ovitrapping was carried out daily for 3 days pretreatment and for 1 day posttreatment (the morning after the spray). Data were analyzed, means separated and percentage change determined as described for adult collections.

Sentinel cage observations: Twenty-five, 3- to 6-day-old, nonblood-fed *Ae. aegypti* females, reared from eggs collected in Santo Domingo, were placed into 25-cm long × 6-cm diam cylindrical sentinel cages constructed from corrosion resistant steel screening (7 × 7 mesh/cm^2). Sentinels in their cages were transported in insulated chests with damp paper toweling to maintain humidity.

Thirty minutes prior to each spray application, one sentinel cage was placed beneath the bed in the front bedroom and another placed in the open area of the living room in each of the 5 homes in which spinners and filter papers had been placed. Sentinel cages were also placed in 5 randomly selected homes from the 25 houses used for adult collections in the control area. Two additional cages were placed outside 2 houses in each treatment area. All cages were collected approximately 30 min after spraying and returned to the laboratory. Mosquitoes were transferred to clean cages approximately 1 h after application, and mortality was recorded at 24 h. Percent mortality data were corrected with Abbott's (1925) formula, transformed (arcsin) and subjected to an analysis of variance procedure (ANOVA [SAS/STAT 1985]) for testing the hypotheses that mortality among treatment regimes, cage locations and dates were equal. Means calculated for treatment regime, sentinel cage locations and date were separated by use of Duncan's (1955) multiple range test ($P < 0.05$).

RESULTS AND DISCUSSION

Malathion was deposited on the filter papers in various amounts at all sample sites (Table 1). The amounts of malathion deposited at all locations were fractions of the amount (5 μg(AI)/cm^2) actually applied. Aerial compared to ground

Table 1. Mean amounts (μg[AI]/cm^2) of malathion deposited on filter papers from ground or aerial ULV adulticide applications in Santo Domingo, Dominican Republic.[1]

Type of application	Paper location	Mean of malathion deposited ± S.E.		
		July 8	July 12	July 22
Ground	Outside	0.69 ± 0.16	0.47 ± 0.20	—
Ground	Beneath bed	0.38 ± 0.10	0.21 ± 0.11	—
Ground	Backroom	0.27 ± 0.05	0.07 ± 0.02	—
Aerial	Outside	1.22 ± 0.16	1.20 ± 0.20	0.98 ± 0.13
Aerial	Beneath bed	0.18 ± 0.06	0.14 ± 0.06	0.15 ± 0.06
Aerial	Backroom	0.21 ± 0.07	0.28 ± 0.08	0.29 ± 0.07

[1] Inside locations $n = 5$; outside locations $n = 15$.

Table 2. Mean droplet size (in μm) of malathion aerosol collected from outside and inside homes after ground and aerial treatments in Santo Domingo, Dominican Republic.[1]

Type of application	Spinner location	Malathion droplets					
		July 8		July 12		July 22	
		VmD	Range	VmD	Range	VmD	Range
Ground	Outside	19.26	14.39–24.13	12.95	9.82–17.67	—	—
Ground	Inside	17.69	7.00–42.12	21.96	17.59–61.65	—	—
Aerial	Outside	18.65	13.54–23.75	21.32	14.75–27.89	17.83	13.82–22.34
Aerial	Inside	19.37	12.64–33.16	19.86	11.54–28.18	15.77	10.52–25.99

[1] Based on 2 spinners/treatment area outside; 5 spinners/treatment area inside; 2 slides per spinner; outside $n = 4$; inside $n = 10$.

insecticide application provided a more consistent pesticide deposition at each location evaluated. Ground applied aerosol dissipated horizontally as evident by greater pesticide deposition in the back room as compared to the front bedroom. Aerially applied aerosol dissipated vertically as evident by greater pesticide deposition in the back room compared with beneath the bed. The VmDs calculated from droplets collected on inside and outside spinner slides, located in all treatment areas (Table 2), were within the reported effective droplet size range of 5–25 μm (Haile et al. 1982).

No significant difference ($P > 0.05$) was determined between the posttreatment mean number of male or female *Ae. aegypti* collected from houses in ground and aerially treated and control areas, or between the mean number before and after a single spraying within a treatment area (Table 3). Wind speed was 6–11 kph at the start of each spraying, approximately 85 degrees to the direction of the spray output on July 8 and 22 and 15 degrees on July 12. These data indicate that although meteorological conditions were favorable for spraying, neither application method (ground or aerial) provided the necessary malathion-*Ae. aegypti* contact to significantly reduce the adult mosquito population within the homes. A sequential spraying effect was found with ground ULV insecticide application significantly reducing the mean number of female *Ae. aegypti* collected in homes after the second spraying (Table 3).

Table 4 shows that the only significant difference in the pre- and posttreatment mean number of eggs collected from ovitraps was from the aerial treatment area of July 22, with a higher mean number after spraying. This posttreatment level was not significantly different from the posttreatment level obtained in the control area, which supports the premise that the aerial ULV application did not affect the naturally increasing oviposition rate at that time.

Effective amounts of malathion from both ground and aerial ULV applications were applied outside the houses as shown by the high

Table 4. Mean daily collections and posttreatment percentage change of *Aedes aegypti* eggs from ovitraps outside homes in Santo Domingo, Dominican Republic.[1]

Sampling period	Mean number of eggs[2,3]		
	Ground	Aerial	Control
Pretreatment July 8	18.1 Aa	21.4 Aa	19.1 Aa
Posttreatment July 9	19.7 Aa	17.1 Aa	20.6 Aa
% change	+9.1	−19.8	+8.0
Pretreatment July 12	51.8 Bab	25.3 Aa	84.7 Bb
Posttreatment July 13	27.8 ABa	29.6 Aa	48.0 ABa
% change	−46.4	+17.1	−43.3
Pretreatment July 22	—	117.4 Ba	100.8 BCa
Posttreatment July 23	—	175.6 Ca	132.6 Ca
% change	—	+58.2	+31.8

[1] Percent change based on [(posttreatment number − pretreatment number)/pretreatment number] × 100; pretreatment $n = 75$, posttreatment $n = 25$.

[2] Means in the same column followed by the same upper case letter not significantly different [$P > 0.05$; Duncan's multiple range test (SAS Institute 1985)].

[3] Means in the same row followed by the same lower case letter not significantly different ($P > 0.05$; Duncan's multiple range test).

Table 3. Mean daily collections and posttreatment percentage change of male and female *Aedes aegypti* adults from homes in Santo Domingo, Dominican Republic.[1]

Sampling period	Mean number of captured adults[2,3]					
	Ground		Aerial		Control	
	Male	Female	Male	Female	Male	Female
Pretreatment July 8	13.6 Aa	14.8 Aa	8.2 Aab	7.4 Aa	6.2 Ab	7.6 Aa
Posttreatment July 9	6.0 Aa	8.4 ABa	10.0 Aa	7.8 Aa	7.0 Aa	7.9 Aa
% change	−55.8	−43.2	+21.5	+5.3	+13.6	+3.9
Pretreatment July 12	7.0 Aa	7.5 ABa	8.1 Aa	5.6 Aa	8.8 Aa	6.7 Aa
Posttreatment July 13	4.0 Aa	4.8 Ba	6.0 Aa	5.6 Aa	5.6 Aa	6.2 Aa
% change	−42.3	−36.3	−26.0	−0.2	−36.9	−8.5
Pretreatment July 22	—	—	13.8 Aa	11.3 Aa	14.1 Aa	12.0 Aa
Posttreatment July 23	—	—	13.3 Aa	8.8 Aa	13.9 Aa	11.8 Aa
% change	—	—	−3.7	−22.2	−1.8	−1.9

[1] Percent change based on [(posttreatment number − pretreatment number)/pretreatment number] × 100; pretreatment $n = 75$, posttreatment $n = 25$.

[2] Means in the same column followed by the same upper case letter not significantly different ($P > 0.05$; Duncan's multiple range test [SAS Institute 1985]).

[3] Means in the same row followed by the same lower case letter not significantly different ($P > 0.05$; Duncan's multiple range test).

Table 5. Percentage mortality of caged *Aedes aegypti* at 24 h posttreatment due to ground or aerial ULV applications of malathion in Santo Domingo, Dominican Republic.[1]

Type of application	Cage location	Mean percent mortality for indicated date[2,3] July 9	July 13	July 23
Ground	Outside	100.0 Aa	100.0 Aa	—
Ground	Beneath bed	36.3 Ba	27.5 BCa	—
Ground	Back room	59.0 Ca	54.3 Da	—
Aerial	Outside	100.0 Aa	100.0 Aa	82.6 Aa
Aerial	Beneath bed	1.9 Da	14.1 Cb	4.5 Bab
Aerial	Back room	2.1 Da	4.6 Ca	4.2 Ba

[1] Ground and aerial application rate of 500 g(AI)/ha malathion; $N = 12$; percent mortality based on [(percent dead in treatment − percent dead in control)/percent dead in control] × 100.

[2] Means in the same column followed by the same upper case letter not significantly different [$P > 0.05$; Duncan's multiple range test (SAS Institute 1985)].

[3] Means in the same row followed by the same lower case letter not significantly different ($P > 0.05$; Duncan's multiple range test).

sentinel mosquito mortality (83–100%) for cages placed outside (Table 5). Sentinel mosquito mortality was significantly higher for ground ULV exposed caged mosquitoes that were placed beneath beds and in living rooms when compared with cages in the same locations in the aerial ULV treatment area. Larger amounts of malathion from ground versus aerial ULV applications were reaching the inside sample sites (Table 1), which could account for the observed higher mortalities. Sentinel mosquitoes were significantly protected from both ground and aerially applied malathion inside houses. In no instance was mortality greater than 60%, and in most instances mortality was less than 30%.

Uribe et al. (1984) reported successful control of *Ae. aegypti* in urban Colombia with aerial ULV applications of malathion; but inconsistent application rates and limited, variable sampling procedures in their study (Uribe et al. 1984) do not allow comparison between their results and the present study. Other studies conducted in the western hemisphere (Eliason et al. 1970, Charles et al. 1979, Chiriboga 1979, PAHO 1982, Tonn et al. 1982), which attributed success to ground and aerial ULV adulticide application, were combined with additional control procedures (larviciding, source reduction and environmental sanitation) also making comparison with this study impossible.

The efficacy of ULV pesticide application against mosquitoes is based on the premise of an airborne insecticide droplet impinging on a flying mosquito (Mount 1970). Although applications can be synchronized with *Ae. aegypti* flight activity, all *Ae. aegypti* are not in flight at the same time. As a result, insecticide-mosquito contact necessary for a significant reduction is difficult to achieve. Giglioli (1979) stated that immediate, 97% minimum reduction of the adult *Ae. aegypti* is necessary to control a dengue virus epidemic. In this study, neither ground nor aerial ULV application methods effected a 97% reduction in adult *Ae. aegypti* populations despite established malathion susceptibility and generally efficient dispersal of insecticide by standard application techniques. One explanation for the low efficacy of both application methods against indoor *Ae. aegypti* is an insufficient number of malathion droplets impinging on individual target mosquitoes. Similar reasons have been suggested for the failure of various ground ULV applications against *Ae. aegypti* in Puerto Rico (San Juan Laboratories 1987). Sequential spraying, although not directly evaluated in this study, may provide the necessary 97% adult *Ae. aegypti* reduction by decreasing the population a small percentage during each successive application. Further basic work on techniques producing increased pesticide penetration of buildings and on flight activity of mosquitoes during ULV application of adulticides could eventually increase our real ability for emergency vector control.

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